INERTIAL CONFINEMENT FUSION

Lawrence Livermore National Laboratory

Monthly Highlights

January 2000

UCRL-TB-128550-00-04

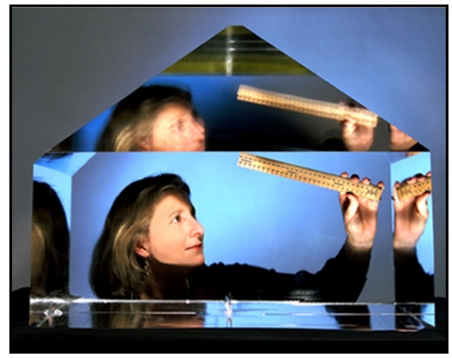
OAB Construction Complete. The Optics Assembly Building (OAB), a cleanroom facility with Class 100 to Class 10,000 areas, has been completed. Line replaceable units (LRUs), which are large, optomechanical assemblies that will populate the 192 beamlines of the National Ignition Facility (NIF), will be assembled in the Class 100 area. Other areas will house the mechanical parts cleaners and optics transfer equipment. Installation of the special assembly, handling, and cleaning equipment required to produce LRUs began in January. The ultrasonic large-parts mechanical cleaner, shown below, is the largest of its type in the world.

An ultrasonic large-parts mechanical cleaner in the OAB.

SEAB Task Force Supports Completion of NIF. The Secretary of Energy Advisory Board's (SEAB) task force says in its interim report Jan. 10, 2000, that it has found no "technical or managerial obstacles" that would prevent completion of the NIF project. The task force, however, points out that there are serious challenges in project management, beampath integration and cleanliness, and optics. But with "appropriate corrective actions, a strong management team, additional funds, an extension of the schedule, and recognition that NIF is, at its core, a research and development project," the task force believes the project can be completed.

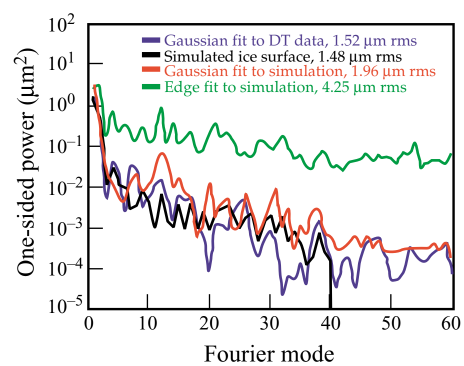
The task force recommends spending more money to solve technical challenges and raising NIF's contingency fund to 30–35% instead of the approved 15%. It also urges that the project include clearly defined roles and lines of authority, an external review, design robustness, integration of research and development efforts with project management, and a phased approach in reaching NIF's performance goals (operating as 96 beams initially and then as 192 beams).

NIF Grows Largest KDP Crystal Yet. The largest KDP (potassium dihydrogen phosphate) crystal ever produced by rapid growth was completed at Lawrence Livermore National Laboratory in January. A salt transfusion during the 52-day growth period brought about the record-breaking size of the crystal boule. The 320-kg crystal is expected to yield as many as 14 doubler plates, a record from a single boule. One hundred ninety-two doubler plates are required in the NIF to convert infrared to ultraviolet light. Completion of this crystal marks the one-third point for planned NIF KDP doubler production.



This record-size KDP crystal was grown in only 52 days.

Smoother Ice Surfaces Inside NIF Capsules Will Aid Ignition. Deuterium tritium (DT) ice-layer surfaces inside cryogenic NIF target layers are smoother than once believed; consequently, they will have smaller amplitude perturbations when imploded—providing more margin for NIF ignition. Recently, a backlit image of a cryogenic target capsule was analyzed using a Gaussian fit to define the internal ice surface position relative to the outside of the capsule. SHELL3D ray trace simulations, using a two-dimensionally bumpy mathematical ice surface with the same power spectrum as the analyzed experimental data, showed that the Gaussian fit correctly reproduced the ice-surface power spectrum and total rms deviation (<30% error in the rms). The previously used edge fit produced errors as large as 1–2 orders of magnitude in the power spectrum and more than a factor of 2 in the rms. These results are being included for baselining ICF ignition target design and fabrication.



Comparison of Gaussian and edge fit to simulated ice surface.

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INERTIAL CONFINEMENT FUSION
Lawrence Livermore National Laboratory

Monthly Highlights

February 2000

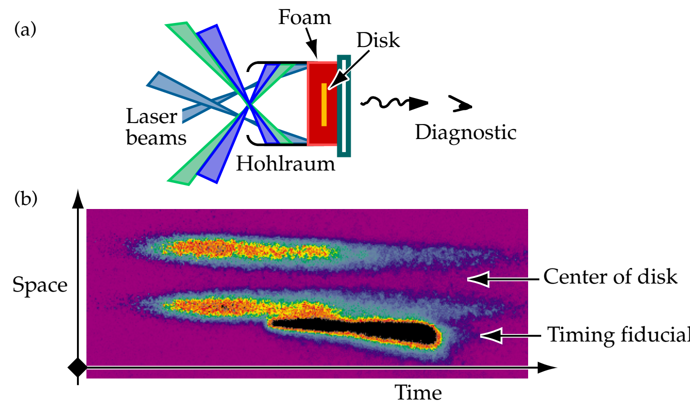
UCRL-TB-128550-00-05

First-Production FAU Delivered. The first-production version of the NIF amplifier frame assembly unit (FAU) has been delivered by the fabricator, General Tool Corp. in Cincinnatti, Ohio. The FAU is the basic building block from which the amplifier enclosures are assembled in Building 381 for both the 11-slab-long main amplifier and 7-slab-long power amplifier. Each FAU is 2 slabs wide by 4 slabs high corresponding to one bundle of beamlines. During the Bldg. 381 assembly process, 2- and 3-slab-long FAUs are precision-aligned and bolted together on rails that are replicas of those in the laser bay.

The top and bottom of the FAU are made from large aluminum castings that incorporate features to accept and align the flashlamp and slab line-replaceable units (LRUs) that are inserted from below. These castings are bolted to side panels, which are fabricated by joining extruded parts using an innovative process called friction stir welding.

The NIF amplifier frame assembly unit.

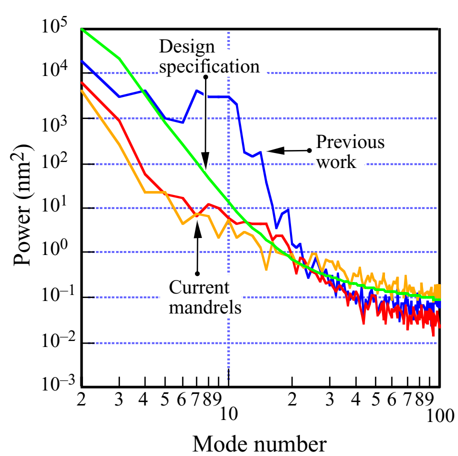
The assembly of amplifier enclosures will take place in Bldg. 381 beginning this summer. The laser slab and flashlamp LRUs will be installed after the amplifier enclosures are installed in the laser bay.



(a) Schematic of an experiment to study radiation transport properties showing an aerogel foam mounted on the side of a half-hohlraum. (b) Breakout of a radiation wave measured via time-resolved x-ray imaging.

OMEGA Experiments Examine Radiation Transport Properties. We have developed, in collaboration with the Defense and Nuclear Technologies Directorate, a testbed to study the local and nonlocal properties of the radiation transport relevant to high-energy-density physics and radiative precursors in astrophysics. Experiments at the OMEGA laser at the University of Rochester Laboratory for Laser Energetics have demonstrated the creation of a diffusive and supersonic regime. Low-density aerogel foams were mounted onto the side of a half-hohlraum, and breakout of a radiation wave was measured via time-resolved x-ray imaging. In the figure above, a disk was embedded in the foam to study how radiation is transported past an opaque object. We compare the breakout of the radiation wave to modeling to test our understanding of the phenomena.

NIF Capsule Mandrels Close to Target Design Specifications. All ignition target capsules except machined beryllium must start from a spherical plastic mandrel upon which the full capsule is built. The sphericity of this mandrel, especially over the critical surface modes less than 100, determines whether the finished capsule will implode to ignition conditions without breaking up from instability growth. In collaboration with General Atomics, we have optimized microencapsulation techniques to meet the required specifications. We developed new additives for the curing baths in which the process occurs—improving dramatically the sphericity by increasing the shell-bath interfacial tension. We also improved final curing and drying techniques.



Power spectra show that recently prepared mandrels (red and orange) come close to meeting design specifications (green).

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Lawrence Livermore National Laboratory

Monthly Highlights

March 2000

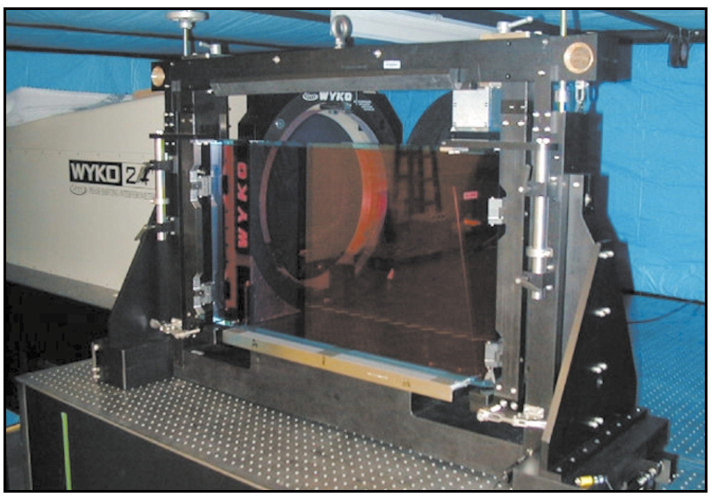
UCRL-TB-128550-00-06

Continuous Glass Melting Improves Laser Glass Yields.

Schott Glass Technologies (SGT), Duryea, Pa., and Hoya Optics, Fremont, Calif., are now demonstrating continuous laser glass melting capability, which is necessary to produce slabs at the rate and yield required for the National Ignition Facility (NIF).

At SGT, production of laser glass in the Pilot II Phase II run will begin in May. In Phase I, which has been completed, about 250 NIF-quality amplifier slabs were produced. In Phase II, the total is expected to be about 580 slabs.

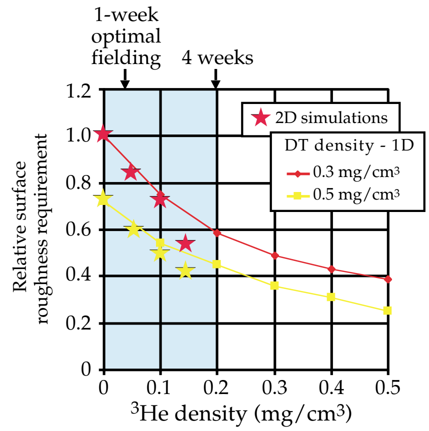
At Hoya, Phase I of Pilot II production has recently begun. Start-up problems appear to be under control, and quality glass is expected by the second half of June.



Interferometer testing of finished SGT amplifier slab.

Effects of ^{3}He in Ignition Targets.

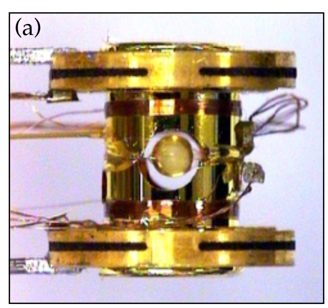
As the tritium decays in a cryogenic target, the resulting ^{3}He is likely to be concentrated in the central gas region of the capsule. Recent simulations have been done to develop a fielding strategy for NIF ignition targets. Quite high concentrations of ^{3}He in the DT gas can be developed; after four weeks, in a baseline target, there will be 0.2 mg/cm^3 of ^{3}He in the gas, which is nominally 0.3 to 0.5 mg/cm^3 of DT. In 1D simulations the ^{3}He has little impact on target performance, but in 2D and 3D simulations, the ^{3}He delays ignition and increases the Rayleigh–Taylor instability growth. This tightens the specifications for surface roughness significantly if the target is more than about one week old since being filled with clean DT. We conclude that the DT fuel should be less than about one week old in order to control the Rayleigh–Taylor instability growth.



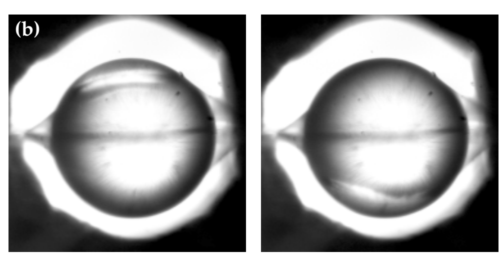
The normalized surface roughness specification for different concentrations of DT and ^{3}He in the gas core. The stars show the results of 2D calculations, while the lines show the results predicted by a 1D model that estimates the Rayleigh–Taylor growth during deceleration.

Cryogenic Hohlraums for NIF Targets.

Indirect-drive NIF ignition targets consist of a DT-filled shell suspended at the center of a hohlraum. Cryogenically cooling the DT fuel below its triple point forms an ice layer on the inner wall of the target shell. Spherical symmetry in the DT ice layer, required for high-yield ignition, is achieved by thermally shimming the hohlraum with two heaters on the hohlraum body. The cooling rods attach to temperature equalizers that symmetrize the hohlraum azimuthal temperature. The additional heaters on the cooling rods allow axial control of the temperature within the He/H_2 gas-filled hohlraum cavity. We have constructed a full-scale shimmed NIF hohlraum (Figure a) and have demonstrated the basic concepts of temperature control (Figure b).



Temperature-shimmed hohlraum



D_2-filled capsule

A temperature-shimmed hohlraum (a) with a D_2-filled capsule suspended at the center. Applying temperature gradient causes D_2 ice to clump on the colder side of the target; reversing the gradient causes the ice to clump on the opposite side (b).

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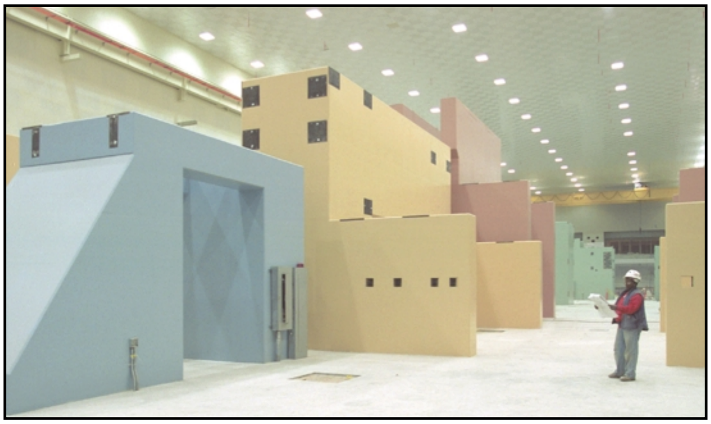
INERTIAL CONFINEMENT FUSION
Lawrence Livermore National Laboratory

Monthly Highlights

April 2000

UCRL-TB-128550-00-07

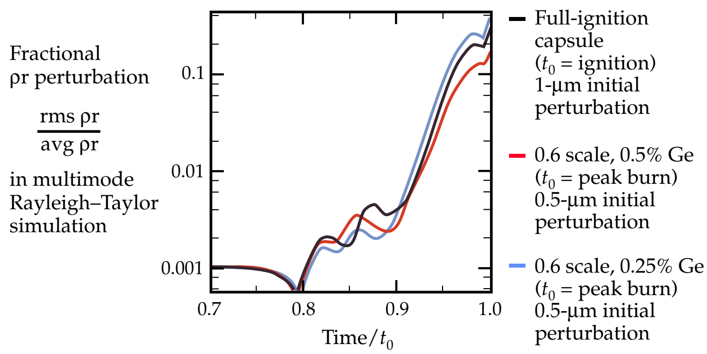
NIF Laser Bay Pedestals in Place. Placement of the concrete pedestals in the National Ignition Facility (NIF) was completed in October for Laser Bay 2 and in



Concrete pedestals in NIF Laser Bay 2.

December for Laser Bay 1. These pedestals, which are monolithic with the laser bay concrete slab, are an essential part of the hybrid concrete–steel support system. With mechanical damping properties and thermal inertia, they will provide support to laser beam optics, optics vessels, beam enclosures, diagnostic systems, and utilities. They will provide optical stability, seismic restraints, and access pathways for services and maintenance. The reinforced concrete pedestals contain embedded steel plates with deformed bar anchors to facilitate attachment to structural steel support members and outrigger supports of optics vessels. There were approximately 85,000 ft^2 of formworks, 270 tons of reinforcing steel, and over 100 tons of embedded steel for all concrete pedestals.

Hydrodynamically Equivalent Implosions Driven with 96 Beams. As the NIF laser is being built, there may be a period of time during which we have the opportunity to do experiments driven with a symmetric configuration of 96 beams, half of the eventual 192. During this period, implosion experiments could be performed that replicate in detail all of the physics of the full-scale NIF target except α-deposition and ignition. The targets are essentially exact scales of the ignition targets, with all times and dimensions scaled by the same factor. The hydrodynamic instability growth can be controlled by varying the concentration of dopant in the ablator.



The instability growth, measured as the growth in the fractional variation in column densiy ρr, plotted versus normalized time, for three cases: a nominal polyimide-ablator ignition target, shown in black, and two different dopant concentrations of Ge-doped polyimide scaled targets. By varying the dopant concentration, the instability growth can be made to bracket the nominal growth in the full-scale target.

NIF Target Bay Roof Construction Completed. The National Ignition Facility target bay roof was placed May 8 after numerous delays due to rainy weather and the process of verifying the shoring system's capacity to support the weight of the 3-ft-thick concrete slab. After the system was checked and approved by an independent inspector, the pouring of concrete, approximately 1200 cubic yards and almost 400 truckloads, began at 12:45 a.m. and continued nonstopped until 3:00 p.m. A concrete pump was kept on standby to ensure continuous operation. Finishers completed the operation by 5:00 p.m. and placed wet curing blankets on the roof slab immediately.

Workers pouring concrete on the NIF target bay roof.

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Monthly Highlights

May/June 2000

UCRL-TB-128550-00-08/09

First NIF Capacitors Received for Testing. The first of the production capacitors for the National Ignition Facility (NIF) capacitor banks have arrived at the Lawrence Livermore National Laboratory (LLNL) for acceptance testing. The NIF system can accommodate up to 5184 capacitors that can each store 85 kJ of electrical energy. It stores over 400 MJ and provides the energy for the flashlamps that power the main laser amplifiers.

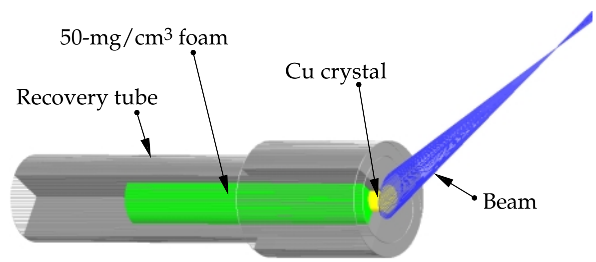
NIF energy storage capacitors manufactured by General Atomics and ICAR.

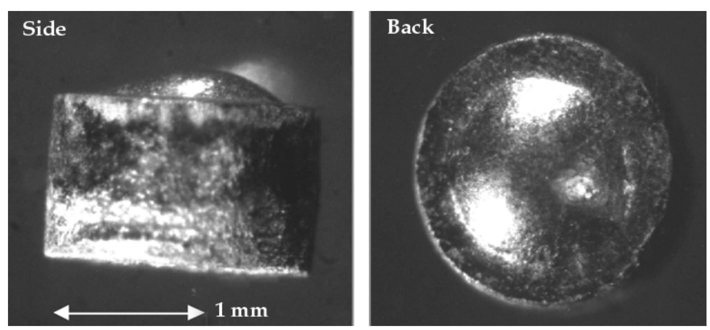
General Atomics, San Diego, Calif., and ICAR SpA., Monza, Italy, provide the advanced metallized dielectric capacitors that experience a gradual loss in capacitance rather than a sudden short-circuit as they near end-of-life. When breakdown of the dielectric in these capacitors occurs, the electrode vaporizes and extinguishes the arc before the heat damages the surrounding material—maintaining the high-voltage integrity of the capacitor.

NIF-Sized DKDP Boule Produced. The first rapid-growth, low-temperature, NIF-sized deuterated potassium dihydrogen phosphate (DKDP) boule was produced in June using horizontal growth. Horizontal growth allows a critical boule dimension (height) to be more easily attained. Horizontal growth at high temperature had previously produced three NIF-sized DKDP boules. Lower-temperature growth with a starting temperature of 45°C instead of 65°C has been shown to improve the 3ω bulk damage resistance of DKDP. This is the first use of low-temperature growth to produce a NIF-sized DKDP boule. The crystal was grown in 42 days and weighed 181.8 kg (400 lb).

The first low-temperature, horizontally grown DKDP boule measured 58 × 84 × 23 cm (23 × 33 × 8.9 in.) and weighed 181.8 kg (400 lb).

Solid-State Crystal Sample Recovery on OMEGA. When a solid-state sample experiences loading by a high-pressure shock, it undergoes plastic deformation by the generation and propagation of lattice dislocations. One method used in gas-gun and high-explosive (HE)-driven experiments to study the response of a material to shock loading is to perform post-shock recovery and lattice level characterization via optical and electron microscopy. A recent series of National Laser Users' Facility experiments





Images of a shocked Cu crystal. The laser was incident on the flat side, causing a "spall bubble" on the back side.

at the University of Rochester's OMEGA laser demonstrated post-shock recovery of single-crystal Cu samples that were shocked by direct laser irradiation. Peak pressures of approximately 1 Mbar were applied to the front surface of the samples. The decaying shock wave propagated through the 1-mm-thick sample and caused spall at the free surface. This technique may be applied to study the post-shock dislocation density in single-crystal samples that are also probed by time-resolved x-ray diffraction during the shock loading and to compare and extend the results achieved with gas guns and HE.

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INERTIAL CONFINEMENT FUSION
Lawrence Livermore National Laboratory

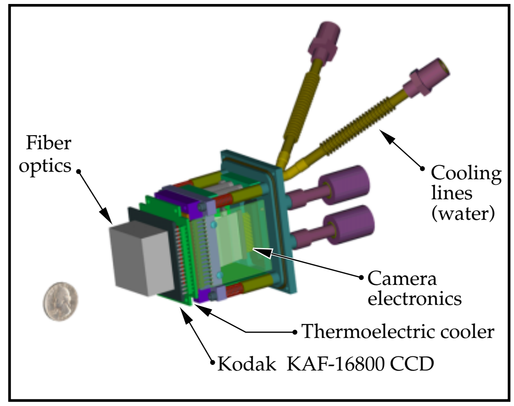
Monthly Highlights
DRAFT—July/August 2000

UCRL-TB-128550-00-10/11

NIF Vacuum End Vessels Installed. Construction of the National Ignition Facility (NIF) laser has begun. Following final completion and acceptance of conventional construction work in the two laser bays, a team of industrial contractors led by M. A. Mortenson Co., one of the nation's 40 largest construction companies, is assembling the first beamline components of the NIF atop reinforced concrete support structures. This team won the NIF Laser assembly contract that was based on a design package jointly produced by Lawrence Livermore Lab's Engineering Department and Parsons Engineering Group Inc., Pasadena. The first stages of the NIF laser assembly involves placing and aligning all of the major optical foundations for the line replaceable units: Laser Mirror 1, cavity spatial filter, periscope, and transport spatial filter (TSF) components. In addition, contractors are installing all the preamplifier support structures and optical foundations of the NIF injection laser system. The first components to be installed were a series of 50-ton steel support structures, the TSF vacuum end vessels (see photograph above).

NIF vacuum end vessel being lifted onto the foundation by a mobile truck crane.

Designs for High-Temperature Diagnostics Presented at Conference. The High-Temperature Diagnostics Conference held in Tucson, Ariz., last June provided an opportunity for all those involved in NIF core target diagnostics to air their concepts. The core target diagnostics, requested by many experimenters, are those that will be first used to diagnose the laser–target interactions. The optical, x-ray, and neutron diagnostic designs were well represented, allowing the NIF user community to discuss them before formal conceptual design reviews are presented, and specifications and schedules are placed under configuration control. Some designs for common packages, such as the charge-coupled device (CCD) camera unit shown at right, used in streak and framing cameras, were shown. The papers will be published in *Review of Scientific Instruments*.



The CCD camera package intended for use in x-ray streak cameras on NIF.

First Finished Amplifier Slabs Received. Zygo Corporation, Middlefield, Conn., completed the first amplifier slabs for the National Ignition Facility (NIF). Zygo will finish the 3,072 amplifier slabs for NIF utilizing laser and cladding glass melted at Schott Glass Technologies, Duryea, Pa., and Hoya Optics, Fremont, Calif. In order to finish an amplifier slab, cladding strips are epoxied onto a shaped laser glass blank. The optic is then ground to final dimensions and polished to meet the NIF wavefront requirements. This optic is the culmination of a five-year effort starting with a program to develop a process for finishing optics to NIF specifications and progressing to a pilot program of full-aperture demonstrations and production-rate optimization.

Final visual inspection of a finished amplifier slab.

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INERTIAL CONFINEMENT FUSION
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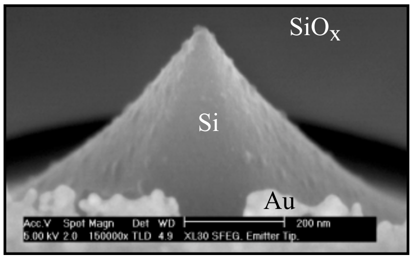
Monthly Highlights

September 2000

UCRL-TB-128550-00-12

New Photocathode Developed.

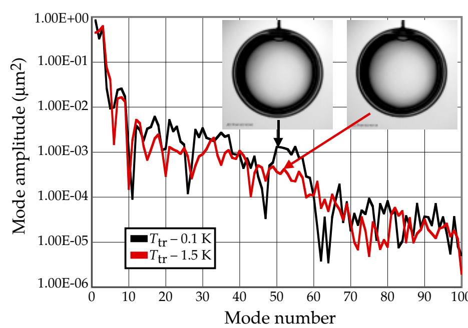
Bechtel Nevada, with support by the Lawrence Livermore Inertial Confinement Fusion and the High Energy Density Experimental Science programs, is demonstrating a novel photocathode based on the photo-field emission of silicon emitters. In photo-field emission, electrons do not have to overcome the potential barrier to escape into vacuum. Due to the high electric field at the tips of the emitters, electrons are emitted through a quantum mechanical process called tunneling. The absorbed photon energy only increases the probability that an electron will be emitted. This silicon-based field-emission photocathode (see photo) has a broad spectral response and is stable in air. It is made up of submicron-size structures fabricated using standard silicon microfabrication processes.



A field-emission electron-microscope image (taken with the FEI XL30 SFEG microscope) of a silicon emitter surrounded by a gold (Au) gate film that is electrically isolated from the substrate by the oxide layer. The presence of the gate film in close proximity to the emitter allows the photocathode to be operated at low voltages and improves its efficiency.

Layering Successful at Equivalent Point Design Temperature.

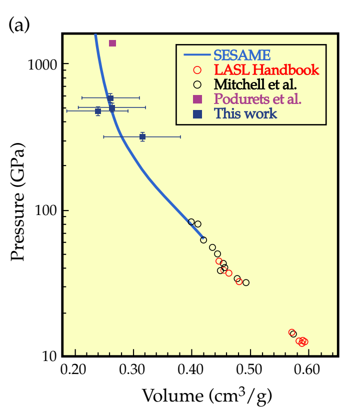
We have achieved smooth layers 1.5 K below the triple point (T_{tr}) using the infrared (IR)-enhanced layering technique. These layering experiments determine the volumetric heating rate (or laser power) and cooling rate required to minimize layer degradation upon cooling a uniform layer to 1.5 K below the triple point. Previous surface roughness experiments showed that high volumetric heating rates helped to smooth solid layers. In recent experiments we addressed the question of whether high volumetric heating rates could also help maintain layer quality as the temperature is lowered. For these experiments, uniform deuterium hydride (HD) layers were formed near the triple point and then slowly cooled to 1.5 K below the triple point under constant IR illumination. At laser powers corresponding to greater than 30 times the beta-layering heating rate (30 Q_{DT}) with a 10 mK/3 min cooling rate, the layers remained smooth (see inserts in the figure).



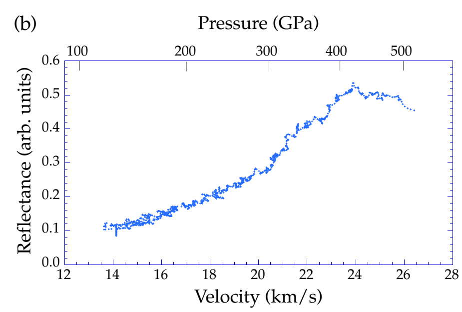
Two images of solid HD layers (inserts at top right of figure) from one layering experiment. Uniform layers have been formed and maintained to T_{tr} – 1.5 K using high IR laser power. The left insert shows the layer shortly after it was formed near the triple point. The right insert shows the same layer after it had been cooled approximately 1.5 K below the triple point using a heating rate of 40 Q_{DT}. The calculated rms for both these images is 1.33 μm. The plot shows corresponding power spectra for these two images. Total cooling time was 7 1/2 hours.

OMEGA Laser Yields EOS and Reflectivity Data for Water.

Most planetary models are constructed from space probe data (gravitational moments, magnetic fields), and typically these models do not include very sophisticated equations of state (EOS), electronic properties, or chemistry. Using the OMEGA laser we have obtained shock-compressed EOS and reflectivity data for water. We have extended EOS data taken with gas guns at 80 Gpa to 500 Gpa. These data cross the ionic-to-electronic conduction transition, which was predicted to occur but where no data existed. These data were measured with the OMEGA VISAR interferometer and will provide rigid constraints for models of Neptune, Uranus, and Europa.



(a) The new Hugoniot pressure-density data for water at pressures up to 500 GPa (5 Mbar).



(b) Reflectivity of the shock. The shock front reflectance in water drops to low levels at approximately 140 GPa shock pressure. The reflectivity data shows a gradual transition to a conducting state and does not reach saturation until about 400 GPa, where the temperature is ~3.5 eV.

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INERTIAL CONFINEMENT FUSION
Lawrence Livermore National Laboratory

Monthly Highlights

October 2000

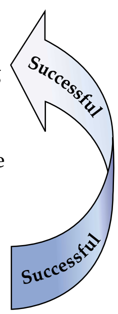
UCRL-TB-128550-01-01

Initial NIF Phase 2 Diagnostics under Consideration. The National Ignition Facility (NIF) core target diagnostics (see definitions below) have been identified, and the responsibilities for their design and construction have been allocated among various institutions involved in NIF. In addition a set of Phase 2 target diagnostics, required to provide the full NIF capability, is under consideration. Eventually some of these Phase 2 target diagnostics will become *facility* diagnostics, operated and maintained by the facility, while others will remain as *user-specific* diagnostics. To address questions relating to these Phase 2 diagnostics, a workshop (one of a series) was held in Tucson, Ariz., on June 22 and 23, immediately following the High Temperature Diagnostic Conference. Expert groups represented laser diagnostics, optical diagnostics, nuclear diagnostics, x-ray imaging diagnostics, x-ray power diagnostics, x-ray spectroscopy, shock physics diagnostics, and detectors and calibration. Each group was asked to (1) identify diagnostic needs for NIF not met by the core target diagnostics, (2) identify which of these Phase 2 diagnostics should ultimately become facility-owned and operated, (3) identify groups actively involved in relevant research and development (R&D), and (4) identify groups who are interested in providing the NIF diagnostics. In addition, estimated costs were requested. A summary table is available on the NIF diagnostic Web site, and from Alan Wootton (email: wootton1@llnl.gov). The next steps include prioritization and allocation of responsibilities for these Phase 2 diagnostics.

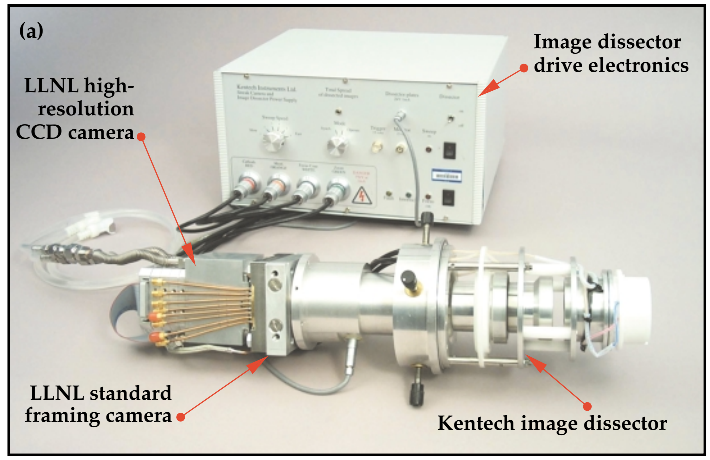
Core Target Diagnostics:
Diagnostics required to measure the interaction of the laser beams with the targets, that have a wide user base and strong programmatic requirements, and that require minimal R&D.

Laser Characterization Diagnostics:
Diagnostics provided to measure the laser beam quality, pulse shape, timing, energy, and power.

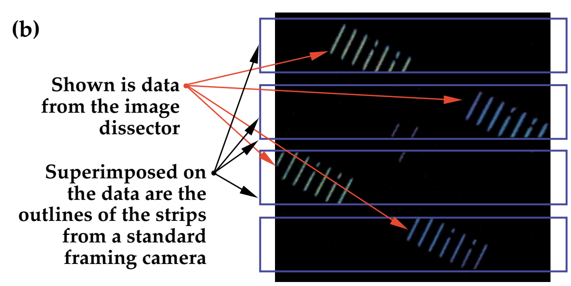
Phase 2 Target Diagnostics:
Diagnostics required for target experiments in addition to the core target diagnostics, e.g., those requiring significant R&D, or of single-user utility.



New X-Ray Framing Camera with an Image Dissector Developed. LLNL in collaboration with the University of Rochester's Laboratory for Laser Energetics (LLE) has demonstrated a new single line of sight (SLOS) x-ray framing camera. The instrument uses an image-dissecting structure, designed by Kentech Instruments Ltd., inside an electron optic tube to produce up to four simultaneous images from a single image incident on the cathode and a microchannel-plate–based device to provide the temporal gating of those images. A series of gated images has been obtained using a short-pulse UV laser source, and the spatial resolution of those images is comparable to those obtained using a more traditional MCP-based system. We have incorporated a standard LLNL x-ray framing camera and a high-resolution charge-coupled device (CCD) data acquisition system to demonstrate the dissector utility (Figure a). Shown in Figure b is an image of a set of slits in front of the photocathode split into four images and then amplified and gated by a framing camera.



An SLOS framing camera with an image dissector.



IMI Contract Awarded. At the end of August the $230 million contract for the NIF Project Integration Management and Installation (IMI) Subcontractor was awarded to Jacobs Facilities, Inc. (JFI). As the IMI Subcontractor, JFI will plan and develop the NIF Beampath Infrastructure System (BIS). The BIS includes all NIF beampath vessels, enclosures, and beam tubes; auxiliary and utility systems; and support structures. JFI will also provide cost and schedule guidance and assume responsibility for construction services (including job management, coordination, quality assurance, and safety). Jacobs Engineering Group, Inc., the parent company of JFI, has served as the Construction Manager for NIF conventional facilities.

For comments about content of the *Monthly Highlights*, contact Bob Kauffman (925) 422-0419.
To get on the mailing list of the *LLNL ICF Monthly Highlights*, *Quarterly Report*, or *Annual Report* send a request to carpenter13@llnl.gov
These reports and other LLNL ICF Program information are available on our Web page at http://lasers.llnl.gov/lasers/inertial.html
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